Coastal Structure Risk and Reliability

Lajes, Azores
Breakwater

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Outline

- Types of coastal structures
- Asset management initiatives
- Risk and reliability overview for coastal structures
  - Loads and Responses
  - Failure modes
  - Reliability methods and tools available
  - Life-cycle analysis method
- Example

Structure Type and Function

Neah Bay, Washington

Breakwater

Wave Protection, Sediment Control

St. Paul, Alaska

Structure Type and Function

Breakwater

Kahului, Hawaii

Redondo Beach, CA, Breakwater 1988, 60-year storm

Buffalo, New York

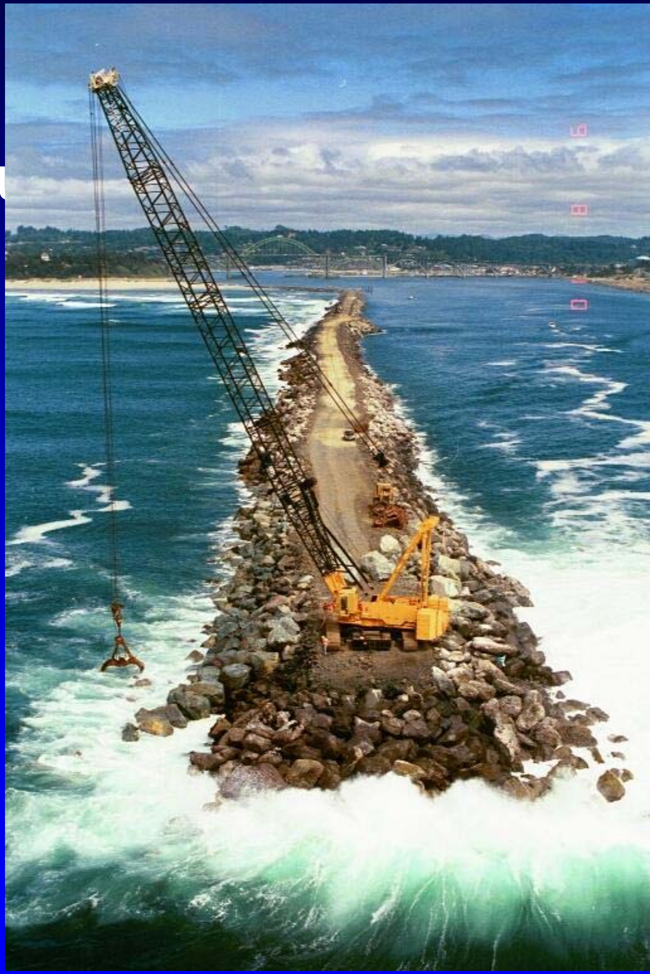
Structure Type and Function

Jetty

Sediment control and wave redu

Umpqua, Oregon

Ocean City Inlet, Maryland



Newport, Oregon

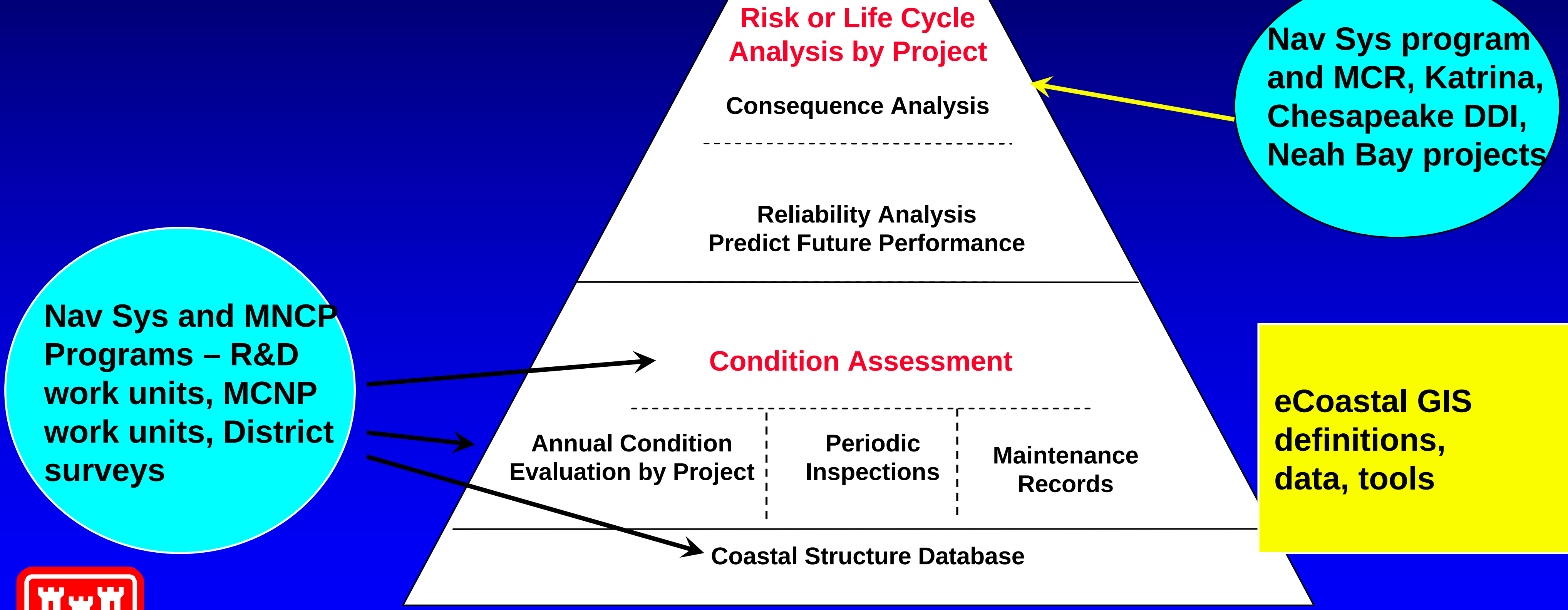
Structure Type and Function

Shore Protection

Structure Type and Function

Levee, Groin, Seawall, Caisson

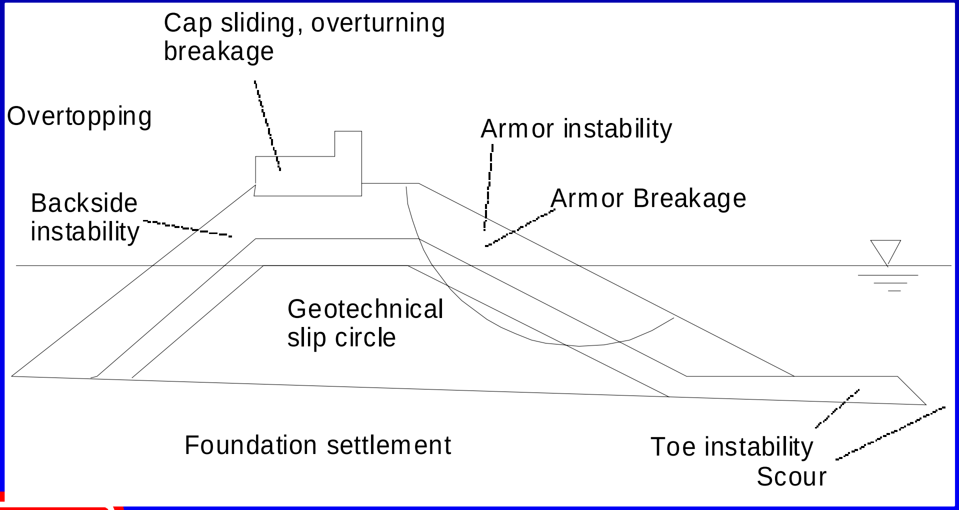
Coastal Structure Asset Management Initiatives



Risk and Reliability Overview

- Forcing: Waves and water levels at structure toe (No earthquake and Tsunami)
- Response: Empirical equations for armor instability, wave overtopping, …

Failure Modes



Failure Modes

Identify applicable limit states and construct event tree

Example of Failure Function

Hudson Equation for armor stability

$$\frac{H_s}{\Delta\, D_n} = (K_D \cot \alpha)^{1/3}$$

Armor Instability on Crest Hinge

Risk and Reliability Overview

Limit State Equations

$$g = \overbrace{\Delta\, D_n\, (K_D \cot\alpha)^{1/3}}^{\text{Resistance}} - \overbrace{H_s}^{\text{Loading}} \begin{cases} < 0 & \text{failure} \\ = 0 & \text{limit state} \\ > 0 & \text{no failure} \end{cases}$$

Some resistance and loading variables are stochastic.
g can be represented as a probability distribution.

Definitions:

Probability of Failure $P_f = \text{Prob}\,[\, g \leq 0\,]$

Reliability $R_f = 1 - P_f$

During a reference period (i.e., return period)

Probabilistic Design Levels

- **Level I:** Deterministic-type design formula with probability-based safety factors → CEM
- **Level II:** Simplified computation of reliability index – approximate failure surface at design point using Taylor series → CEM, CEDAS
- **Level III:** Actual distributions of stochastic variables are applied or computed ex. Monte Carlo simulations → EST, @RISK

Life Cycle Analysis

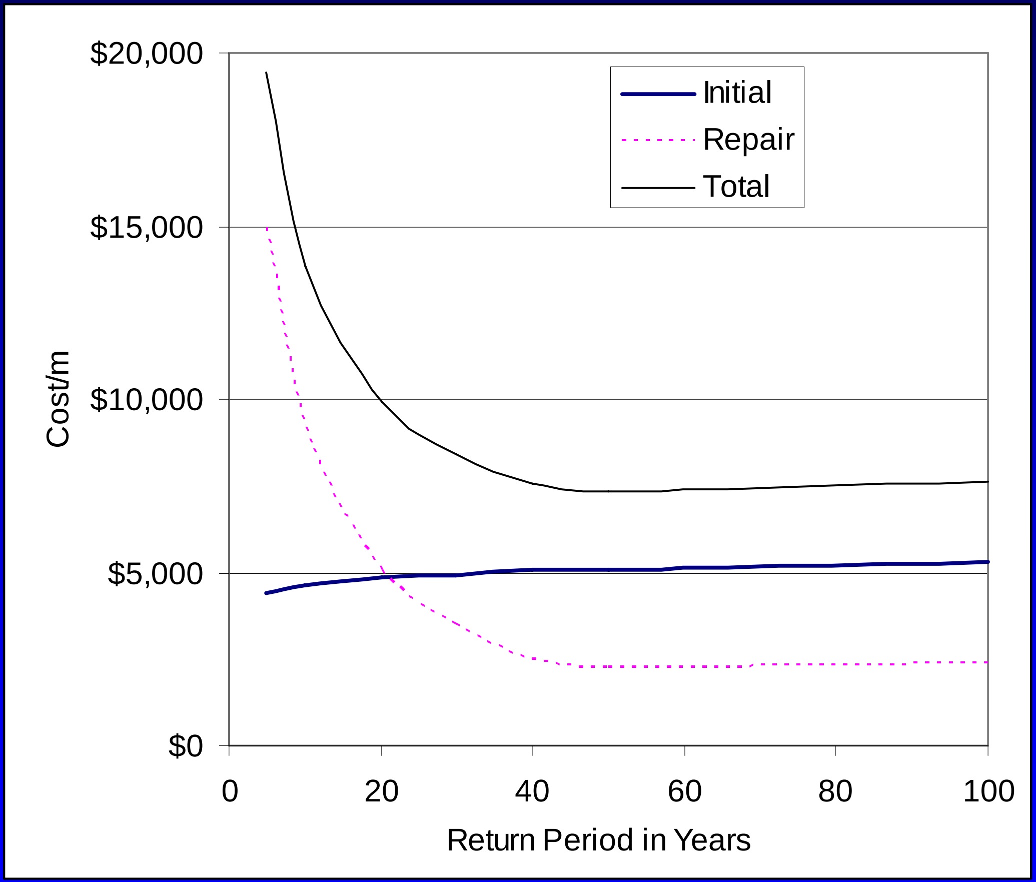
CEM Chapter V-1 "The life cycle approach deals with multiple realizations of possible evolution of the project with time during the span of its design life. The suite of life cycle realizations is constructed with consideration of the probabilities of key variables."

Can't do life cycle analysis without damage function

Life Cycle Analysis

Goals

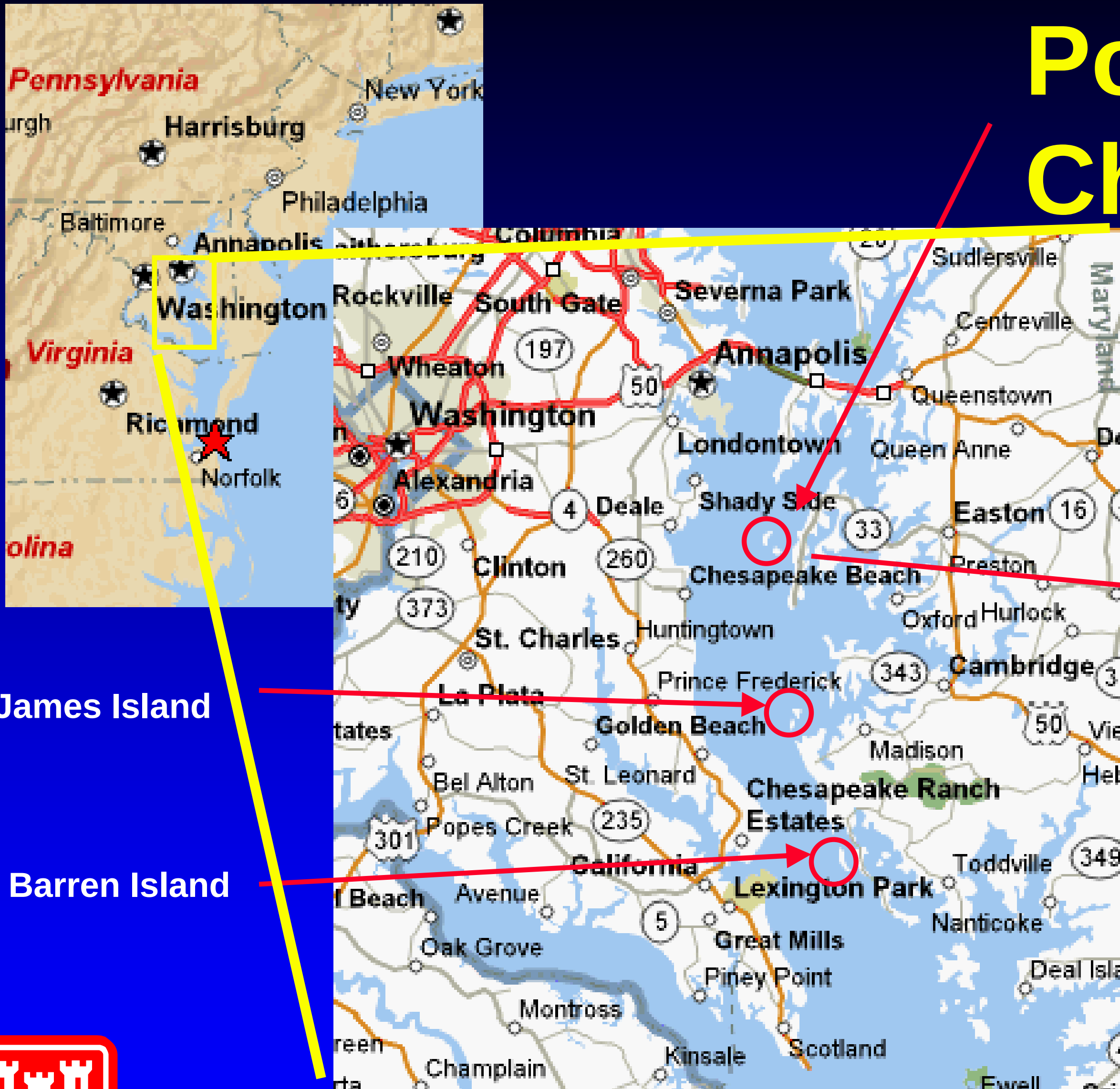
- Minimum p.w. cost of varied alternatives
- Safety level or probability of exceeding various limit states
- Impact of repair policy (Cost, environmental, downtime, catastrophic damage)



Storm Suite Simulation

- Monte Carlo from theoretical extremal distributions
- EST - Empirical Simulation Technique
- WELS – Wave/Water Level Empirical Life Cycle Simulation
  - Simulate future times series statistically similar to past
  - Avoids complex fitting to theoretical distributions
  - Time dependent
  - Maintains complex nonlinear correlations between many parameters
  - Reproduces phase related information - slowly varying storm intensity (El Nino)

Poplar Island, Chesapeake Bay



James Island

Barren Island

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Project Objectives

- Dredge disposal site
- Retain clean dredge material
- Restore eroded island
- Establish natural island habitat for birds, fish, etc.
- Low maintenance

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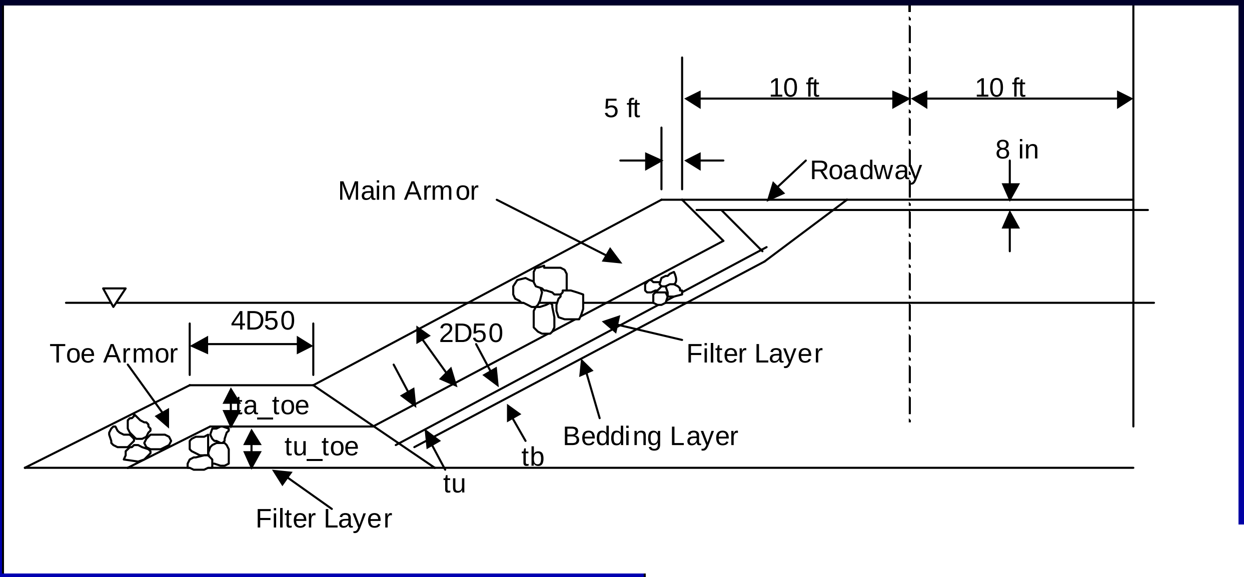
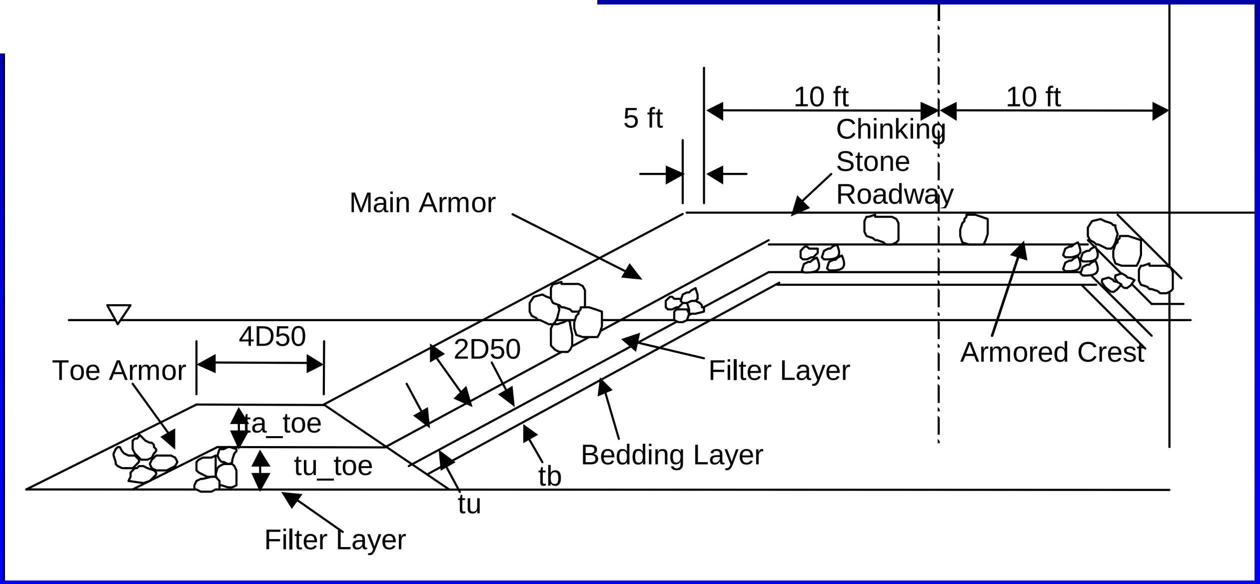


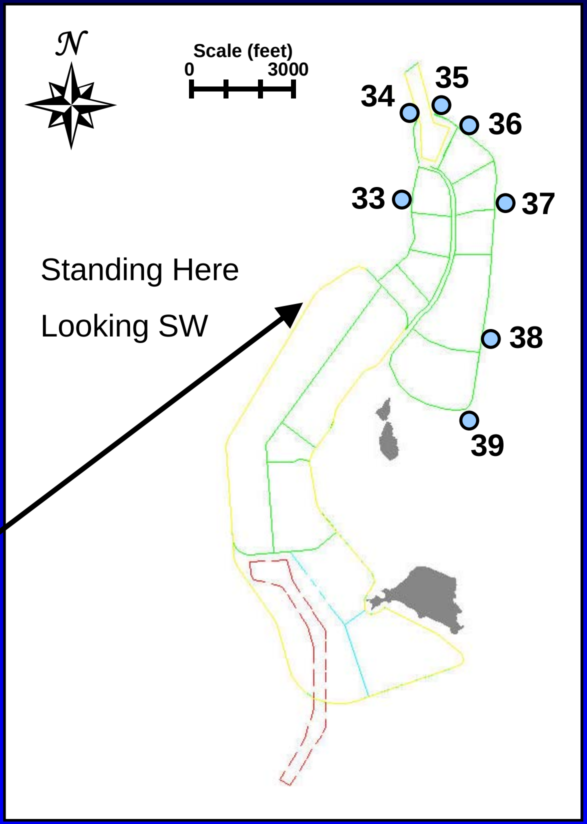
Unarmored Crest Alternative

Armored Crest Alternative



Historical Waves

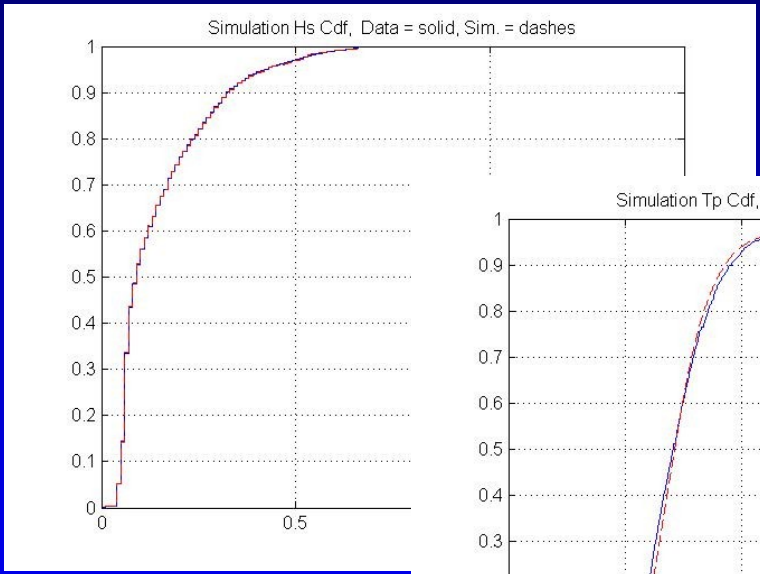
Hindcast 150 years of waves and water levels and transformed waves for 39 stations - Look at Station 33



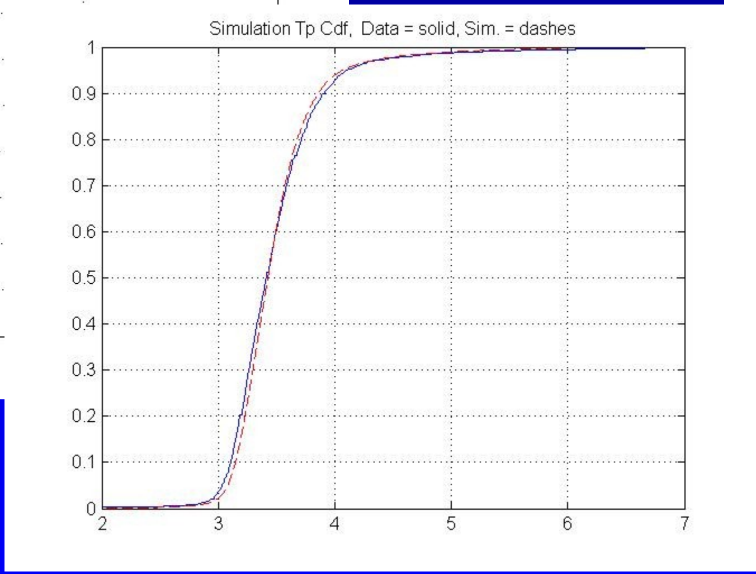
Poplar Island

Wave/Water Level
Empirical Life Cycle Simulation

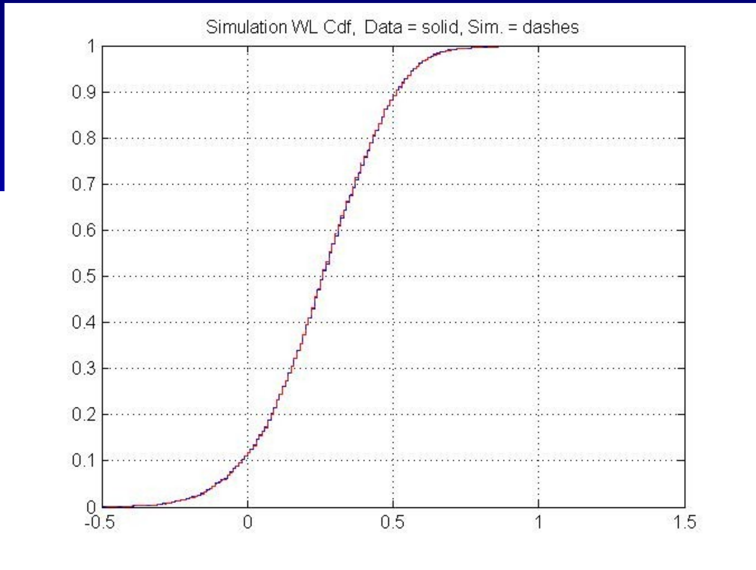
Cumulative Distributions - Historical and WELS



Wave Height, Hs



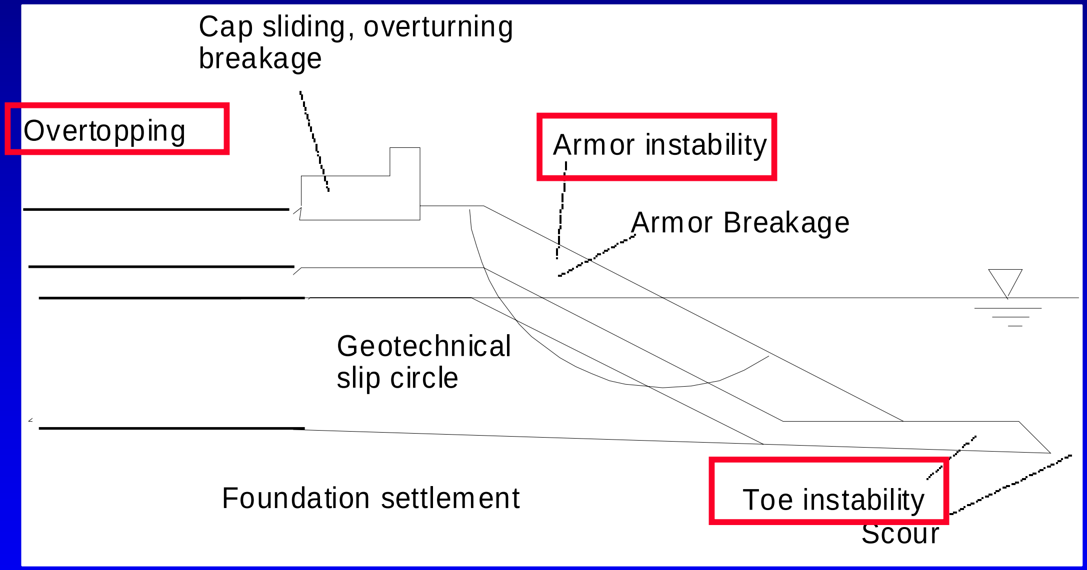
Peak Wave Period, Tp



Water Level, h

Limit States or Failure Modes

Identify limit states, performance functions, and construct fault tree or event tree

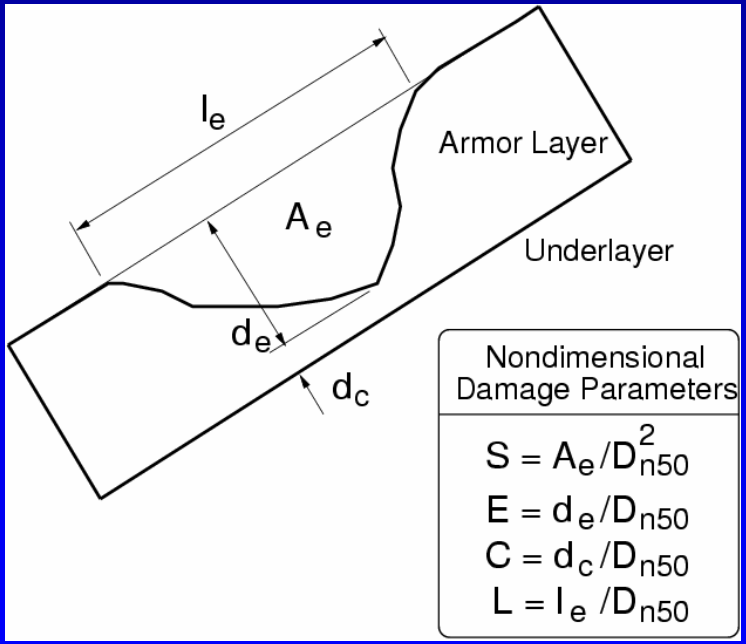


Damage Classes

Initial damage: *S* = 0 - 2

Intermediate damage: *S* = 2 – 12 (used S=8)

Breach Failure: Underlayer exposed *S* = 8-20 (used S=18)



Empirical Life-Cycle Simulation

Preliminary Analyses

Hindcast historical waves and water levels and transform waves to representative stations – WIS, WISWAVE, STWAVE, ADCIRC, CEDAS

Determine extremal wave statistics for 5 –100 year return periods - CEDAS

Simulate future wave and water level climates – EST, WELS

Determine input variable ranges, repair rules, unit costs, fixed costs, extraneous costs of repair

Cross-Section Design

Design structure cross-section at each station for various return periods

Determine initial quantities and costs

Cross-Section Analysis

Step through time series of wave and water level determining eroded area, runup, overtopping, transmission

Accumulate damage and check against repair rules

Repair if required and sum PW costs

Accumulate all present worth costs

Output individual and total stats for damage/repair/costs

Programs LC-COST-REV and LC-COST-BW

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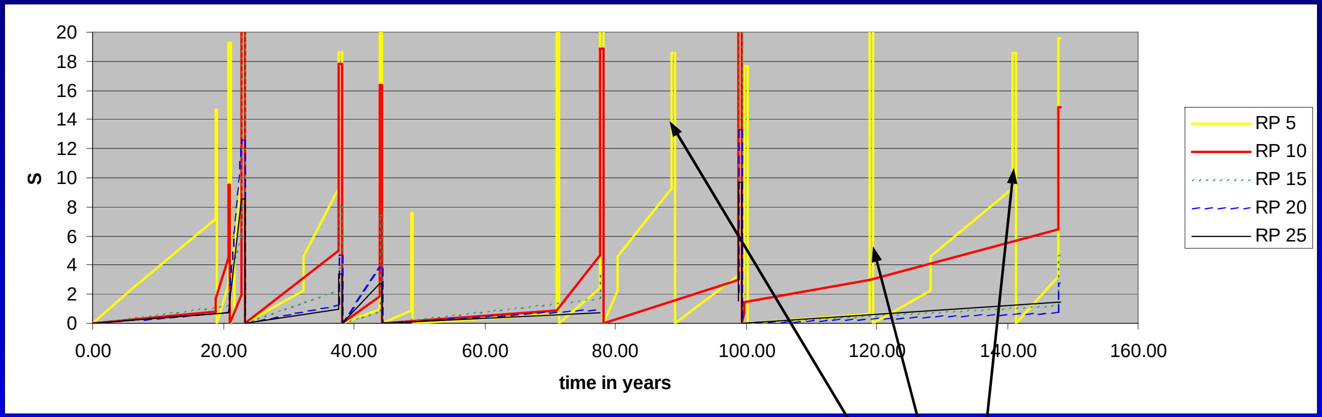
Damage Accumulation and Repair History



Major Maintenance

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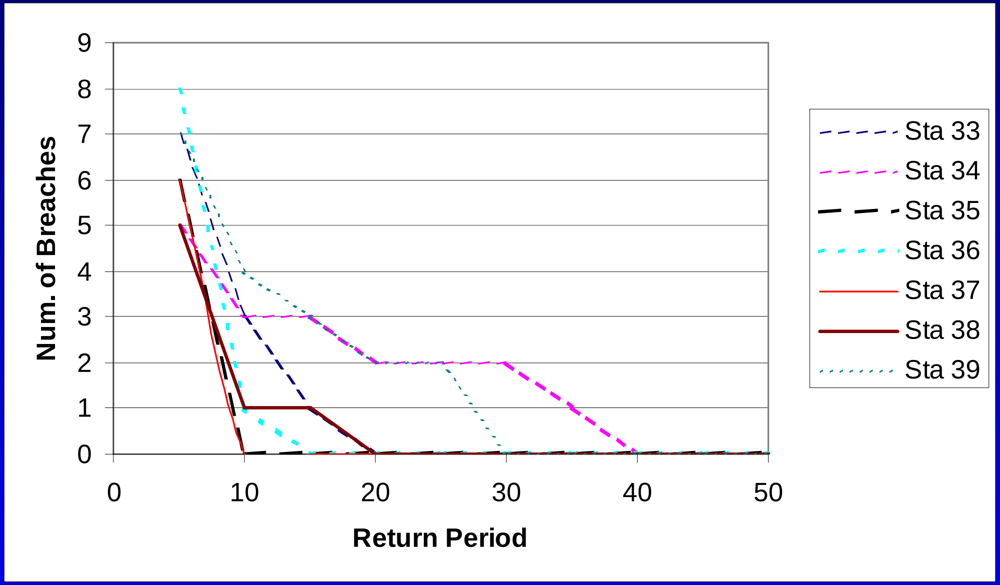
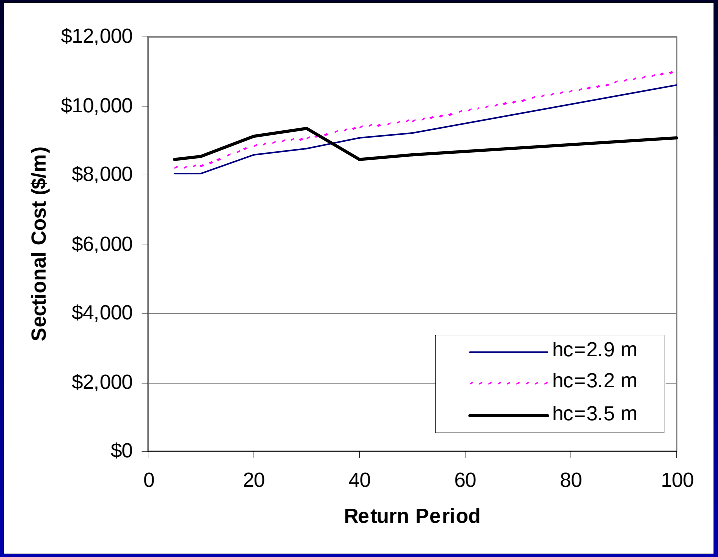
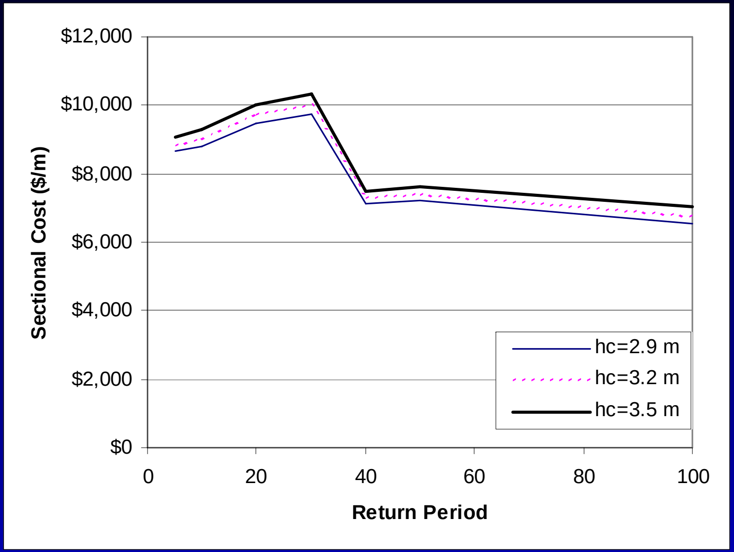
Number of Breaches due to Armor Instability



Station 33 Total Cost

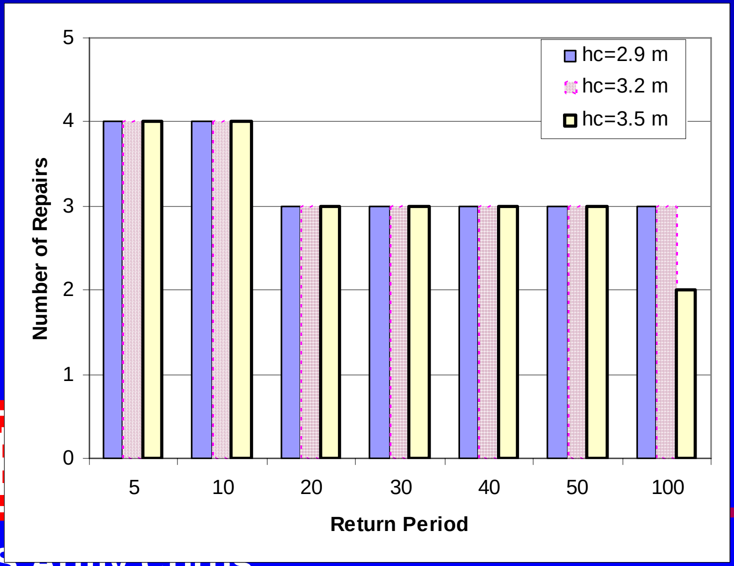


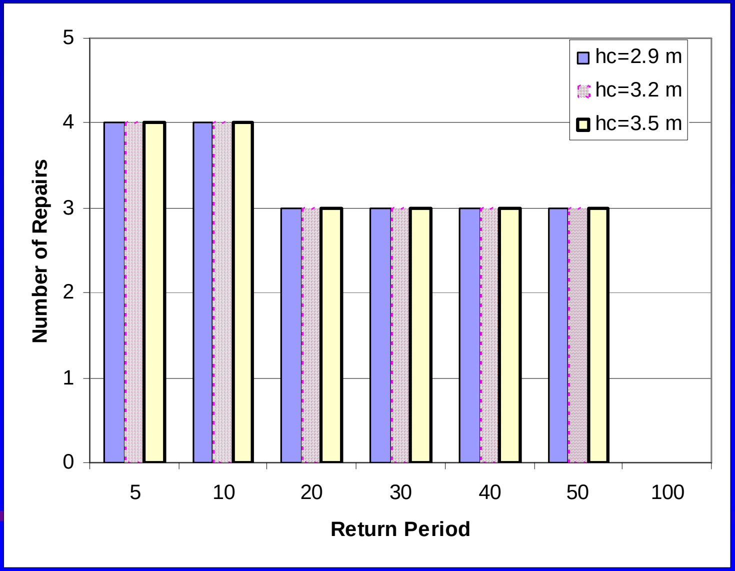


Unarmored Crest

Armored Crest

Number of Repairs





Summary

- ELS - risk analysis methodology
- Time series simulation
- Incorporate time dependent phenomenon into design process
- Useful for rubble mound structure design/optimization
- Minimize overall project costs and unexpected maintenance or environmental/collateral damages

Sunrise at Duck, NC